NEXT STEPS IN DEEP SPACE

toward a permanent human presence in space…
for scientific exploration of the solar system and the Universe

A Cosmic Study by the International Academy of Astronautics

The Next Steps in Exploring Deep Space

Goal

To provide a vision for the scientific exploration of space in the 21st Century

Characteristics

- A logical, systematic, evolutionary architecture
- Using integrated robotic and human exploration
- To enable permanent human exploration of the solar system
- Human exploration of Mars is the ultimate goal in the next decades
- Treats human space exploration as a global enterprise
- Not a strategic plan or a product of any space agency
- Not a technical report; emphasis is on principles, architectures, and identification of required trade studies

Status

- Interim reports at World Space Congress (Oct '02) and IAC (Oct '03)
- International workshop at ESTEC (Sept '03)
- Peer review completed July '04

A strategy for science-driven exploration

Guiding principles:

- Address questions of broad public and scientific interest
- Determine the goals first, then derive destinations and a plan
- Utilize robots where capable and humans where required

Desired outcome:

- A systematic plan for continuous exploration of space, to go wherever we choose to go
- Flexible--adjust destinations to manage cost and risk
- Affordable--no ‘Apollo-like’ bulge, set annual investment level
- Sustainable--progressive set of goals to maintain public interest

Approach: set exploration goals first, then destinations

- First determine “why” society should support such an enterprise
- Then determine “what” the goals are to satisfy these imperatives
- From the goals determine “where” and “how” to accomplish them
- Then devise a logical, systematic and evolutionary exploration architecture to achieve the goals

The Imperatives: Why Explore Deep Space?

To Explore - the cultural imperative

- Expand the frontiers of human experience
- Fulfill the human need to advance and learn
- Inspire, educate, and engage our youth and the public

To Understand - the scientific imperative

- Knowledge and understanding of what surrounds us in space
- Answers to fundamental questions of our origins and destiny
- Advance and sustain human experience and technological progress

To Unify - the political imperative

- Toward a global endeavor without national boundaries
- Toward mutual achievement and security through challenging enterprise
- Toward human utilization of the solar system

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Fundamental questions lead to exploration objectives: What are the goals and where do we need to go?

Where do we come from?

- Determine how the universe of stars and planets began and evolved
- Determine the origin and evolution of Earth and its biosphere

What will happen to us in the future?

- Determine the nature of the space environment and cosmic hazards to Earth
- Determine the potential for permanent human presence in space

Are we alone?

- Determine if there is or ever has been other life in the solar system
- Determine if there are life-bearing planets around other stars

These exploration objectives lead to four destinations which can be reached by humans in the next 50 years…

Sun-Earth L2 *The Moon* *Near-Earth Objects* *Mars*

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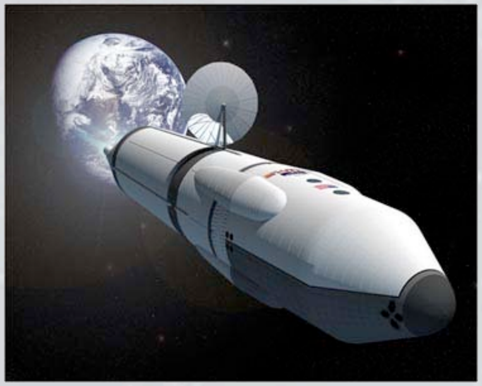
Destination: Sun-Earth L2

A constellation of space telescopes

- Survey the Universe across the spectrum and to the beginning of time
- Observe the process of planetary system formation in the galaxy
- Search for terrestrial planets around other stars
- Search for evidence of life in the spectra of extra-solar planets



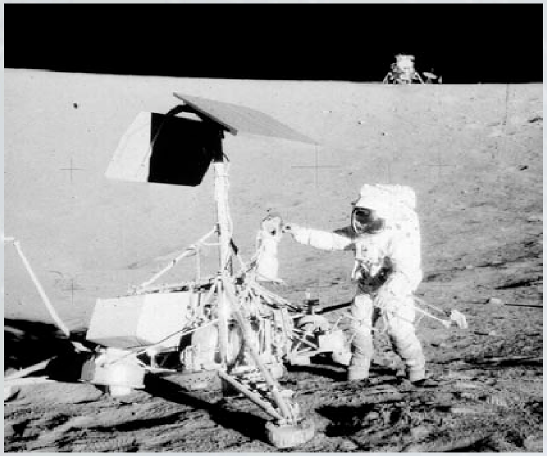
Exploration architecture

- Initial step: “Geospace Exploration Vehicle” provides access from LEO
- Capitalizes on human capabilities for assembly and maintenance
  - Telescope emplacement and servicing to enable *revolutionary* discoveries
  - Preparation and experience for later interplanetary voyages
- SE-L2 is both an energy-efficient “gateway” *and* a key scientific destination

Destination: Moon

Lunar outposts for exploration on the Moon

- Search for evidence of the origin of the Earth-Moon system
- Determine the history of asteroid and comet impacts on Earth
- Obtain evidence of the Sun's history and its effects on Earth through time
- Search for samples from the earliest episodes in the history of the Earth
- Determine the form, amount, and origin of lunar ice



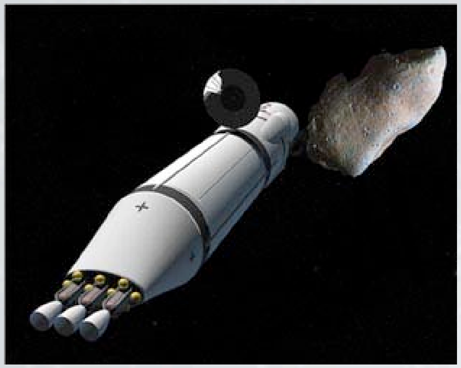
Exploration architecture

- A proving ground: *Learn to explore* the way we will ultimately explore Mars
- Transportation systems can be common with SE-L2 requirements
- Extended human presence on the Moon is an important cultural milestone

Destination: Near-Earth Objects

Field exploration of asteroids

- Survey the diversity and composition of NEO's
- Determine the bulk properties and internal structures of NEO's
- Determine utility of NEO's as potential resources for materials in space and how we might mitigate future Earth impacts



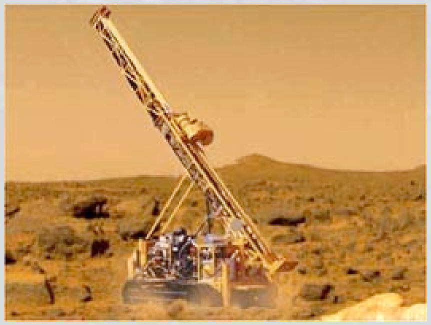
Exploration architecture

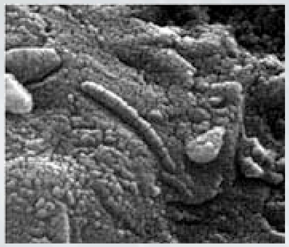
- An intermediate deep space destination to test a human Mars expedition
- Cargo and crew travel separately from SE-L2 gateway to minimize crew flight time
- High degree of commonality with SE-L2 and lunar infrastructure

Destination: Mars

Outposts on Mars - robots & humans working together

- Determine the geological and climatological histories of the Mars
- Determine the history of water and its distribution and form on Mars
- Search for evidence of past and current life on Mars
- Establish a permanent human presence on Mars - the most Earth-like planet





Exploration architecture

- Cargo travels separately via NEP; crew rendezvous with cargo at Mars
- All exploration equipment and habitats arrive *before* crew to reduce risk
  - Emplacement in a robotic outpost to prepare surface infrastructure
- Phobos/Deimos a likely first destination in Martian system to reduce incremental investment; high commonality with NEO infrastructure

The Next Steps in Exploring Deep Space

A goal-driven strategy…
a stepping-stone approach

- No *single* destination for human spaceflight-- exploration and discovery will continue to draw us into the solar system
- A logical progression to successively more difficult destinations--*Mars is the goal* that frames our investments in the next 50 years
- An evolutionary approach leading to human presence at the Moon, Sun-Earth L2, NEO’s, Mars
- Incremental investments and important discoveries ensure sustainability--adjust destinations and schedule as necessary to manage cost and risk

A Mission Design and System Architecture

Robert Farquhar

Ben Clark

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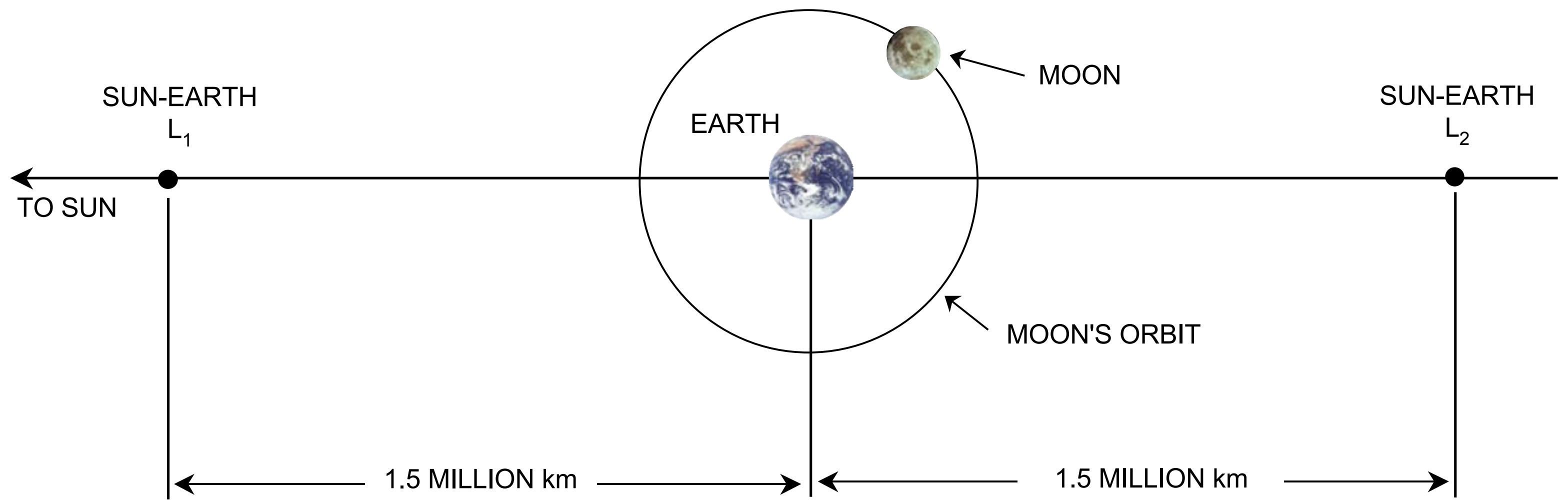
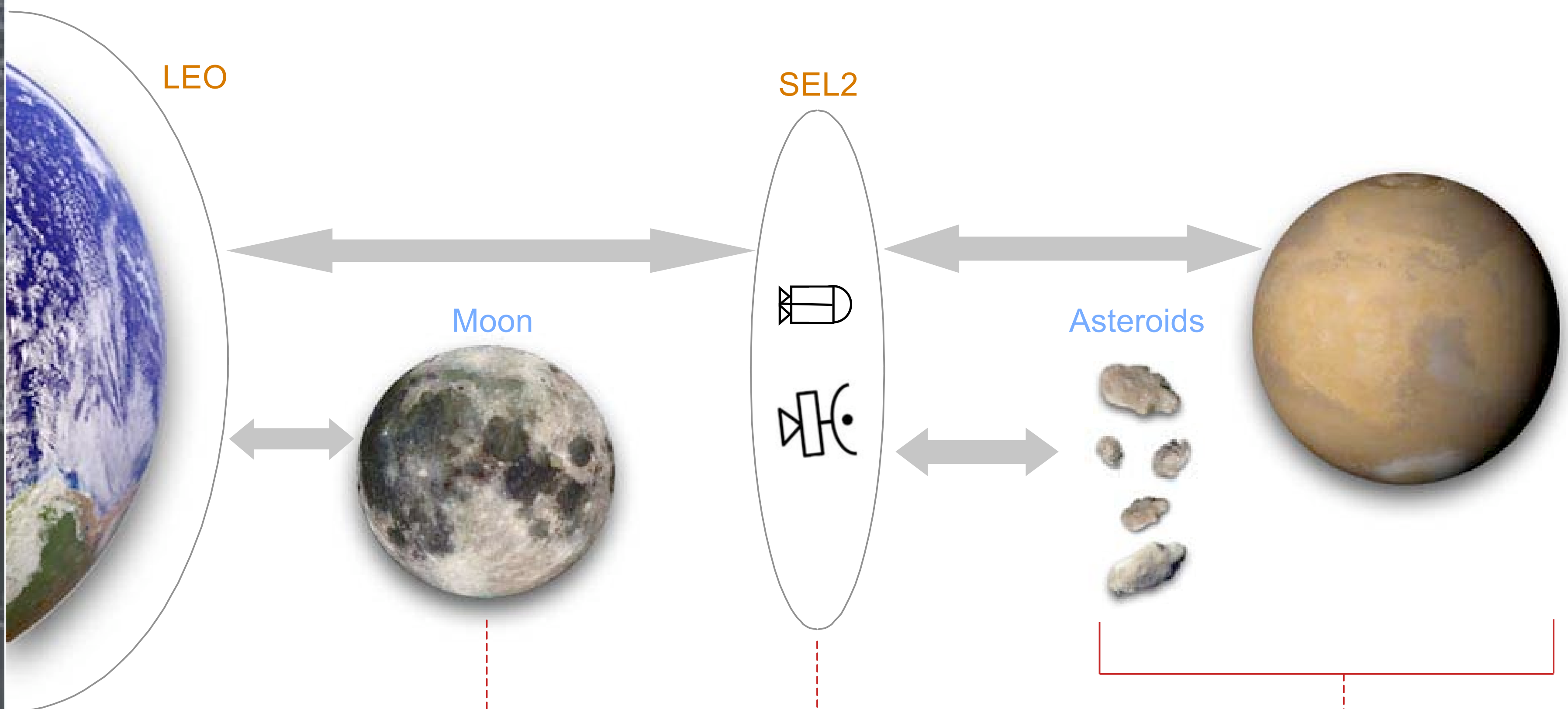
Destinations in Geospace



Why Sun-Earth Libration Point L2?

- Unobstructed view of the Universe ideal for next-generation space observatories
- Dynamically stable, benign thermal environment, continuous communications
- Easily accessible using low energy orbits or low-thrust propulsion
- Efficient gateway to more distant destinations - located at the edge of Earth’s gravitational influence

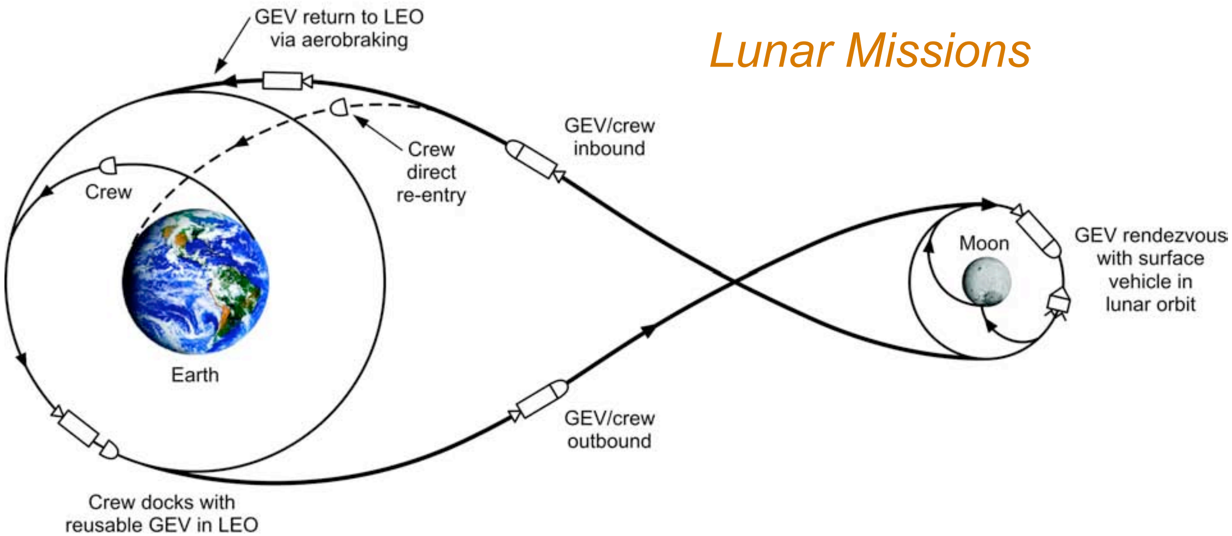
Exploration Architecture



Achievement:	**Robotic precursors and human expeditions**	**Robotic observatories with human servicing**	**Robotic and human exploration and utilization**
Architectural benefit:	***Test and validation of human systems***	***Staging point for deep space exploration***	***Sustained human presence in the solar system***

Geospace Mission Scenarios

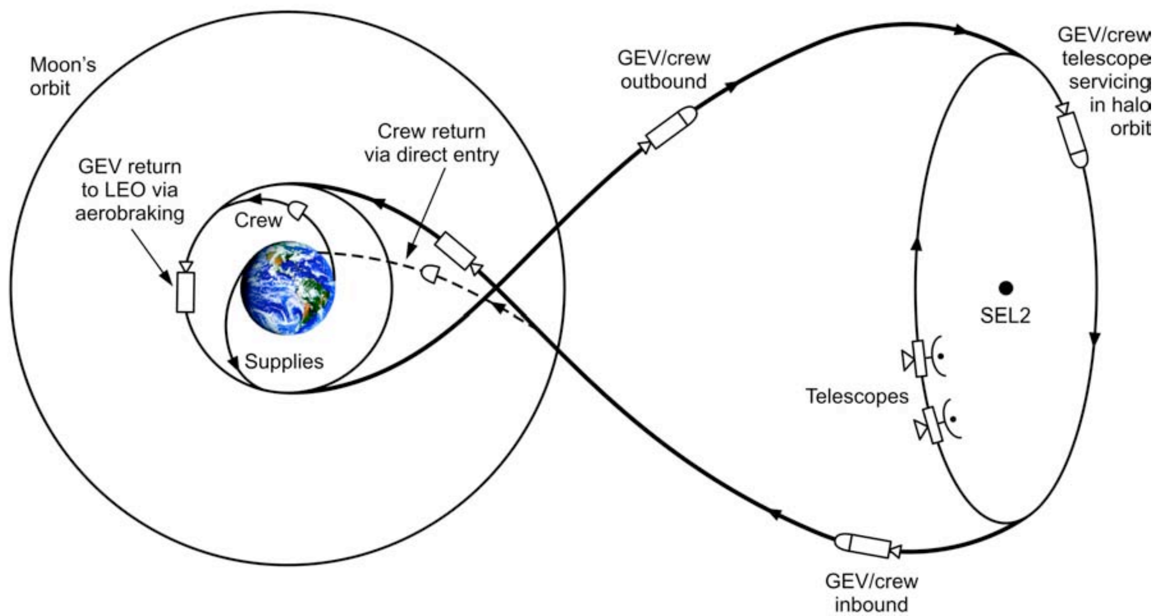
Lunar Missions



- Geospace Excursion Vehicle (GEV) with Apollo-style reentry capsule, crew 3-7, 50 day missions
- GEV solar powered with fuel cells, chemical propulsion ~6km/s Del-V
- GEV reusable; stationed in LEO
- GEV dedicated to crew, cargo travels separately

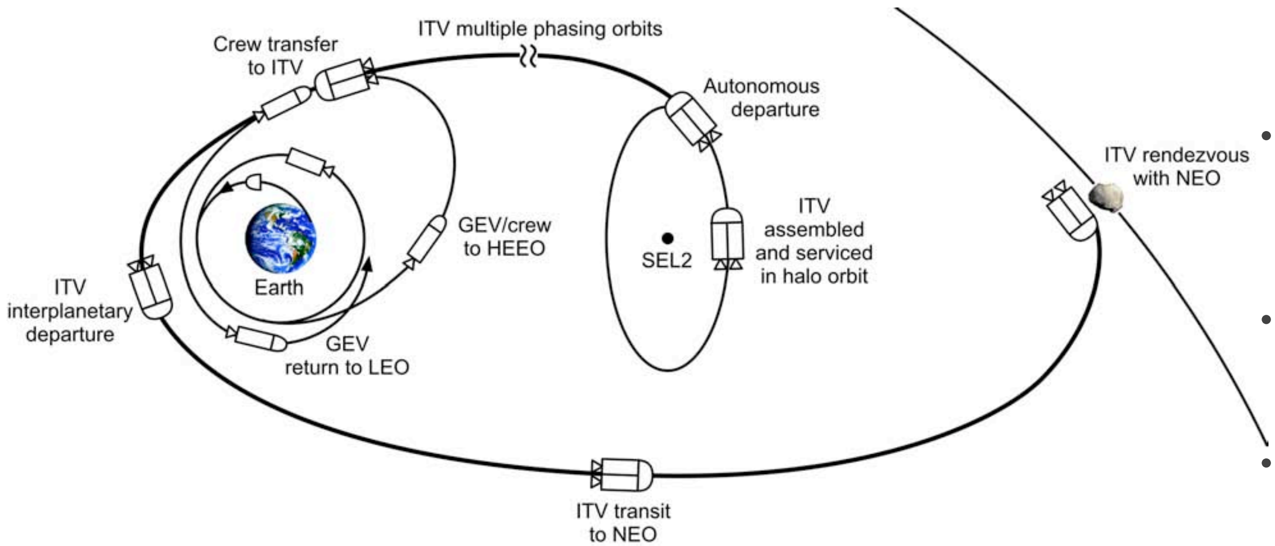
Sun-Earth L2 Missions

- GEV/crew rendezvous with observatory assets in SEL2 halo orbit
- Crew direct re-entry; GEV robotically transfers/aerobrakes back to LEO
- Total mission duration ~50 days including 15 days at SE-L2



Interplanetary Mission Scenarios: NEO's and Mars

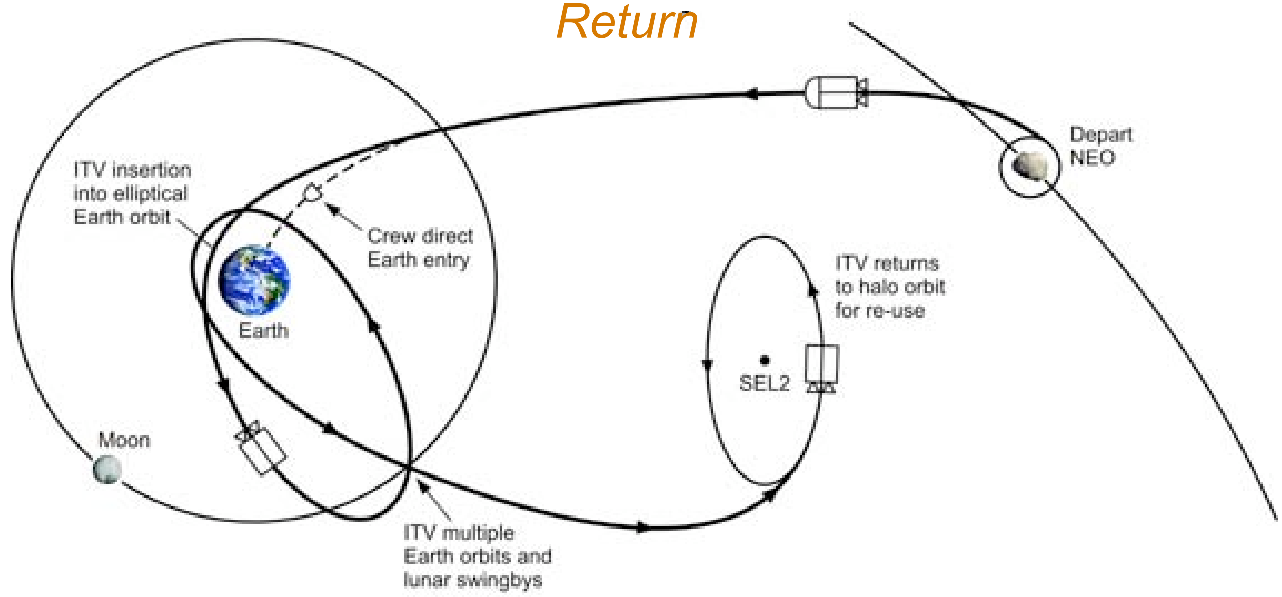
Outbound



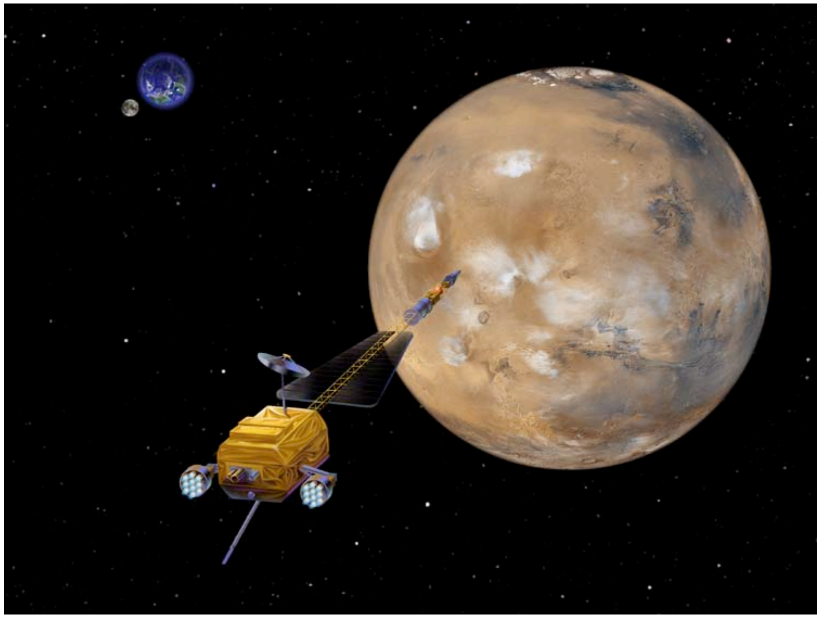
- Interplanetary Transfer Vehicle (ITV) stationed and provisioned at SEL2
- ITV reusable, modular upgrade from GEV, crew transportation to/from NEOs and Mars
- Chem propulsion ~8km/s, solar power, 5-7 crew, 1-3 year missions
- Cargo travels separately to destination for rendezvous

- Crew direct re-entry; ITV robotically transfers back to SEL2 via propulsion and lunar swingbys
- Mission durations 6-12 months for NEO's, up to 3 years for Mars
- ITV re-fueled and serviced at SEL2 in preparation for next mission

Return



Dedicated Cargo Delivery

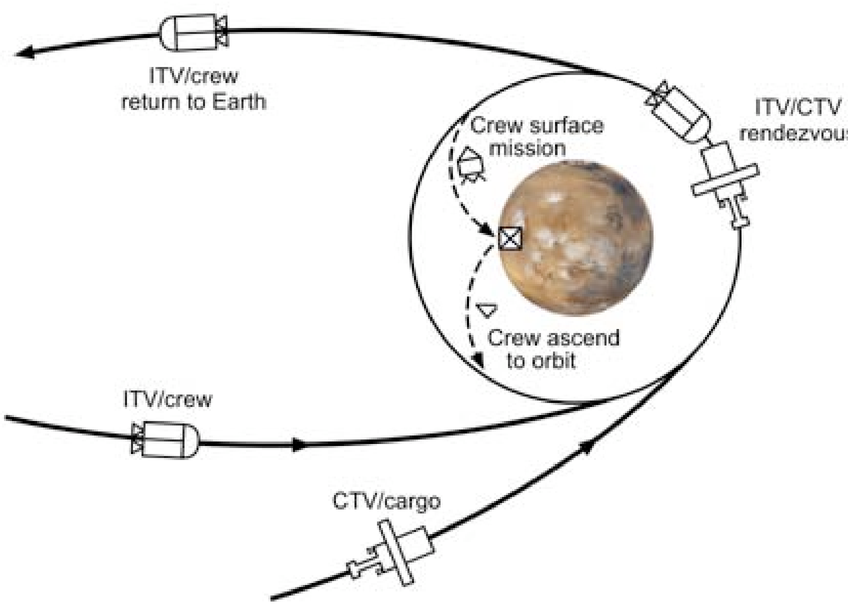


Separation of crew and cargo is an architectural principle

- Minimizes mass and thus flight time of crew vehicles
- Enables emplacement of critical assets in advance of crew departure from Earth
- Highly-efficient Nuclear Electric Propulsion can deliver large masses to destinations
  - NEP technology also enables important robotic science missions

A Mars Robotic Outpost

- Pre-emplaced scientific equipment and infrastructure
- Enhances crew safety and productivity
- Intelligent integration of robotic-human capabilities optimizes science return



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Building Block Capability Development

- Architecture should require just one new *major* capability for each step
- Enables management of incremental investments and mission risk
- Major developments are coupled with evolution in other required capabilities
- Gradually builds the suite of capabilities required for Mars exploration and a sustainable presence in the solar system

Step	*Destination*	*Major New Capability*
1: Beyond LEO	Sun-Earth L2, Moon	Geospace Exploration Vehicle (GEV)
2: Deep Space	Near-Earth Objects	Interplanetary Transfer Vehicle (ITV)
3: On to Mars	Mars Orbit, Phobos/Deimos	Cargo Transport Vehicle (CTV)
4: Down to Mars	Mars Surface	Mars descent/ascent system, habitats, tools

Guiding Principles of the Architecture

Goal-driven

- Destinations must be scientifically and culturally compelling
- Select destinations for which human capabilities are both suitable and beneficial
- Rigid schedules do not drive development decisions

Separate cargo and crew

- Maximize efficiency and safety by focusing transportation tasks
- Dedicated cargo vehicles sent in advance for rendezvous at destination

Stepping-stone approach

- Flexible sequence of destinations and missions, responsive to discoveries and technological progress
- Goal is to require just one major new capability per destination

Emphasize use of existing transportation tools

- Require no fundamentally new and expensive propulsion systems or launch vehicles
- Emphasize astronaut capabilities of in-space assembly and refueling of re-usable systems

Engaging the Global Community: Policy and International Cooperation Considerations

James V. Zimmerman

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ASSUMPTIONS

- Exploration of space is intrinsically a global enterprise
- Multiple exploration “visions” with differing goals will emerge
- Most countries prefer roadmaps that do not depend on others for success

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Engaging the Global Community

Potential near-term steps toward meaningful international collaboration:

- Establish an international forum for information exchange, coordination, and cooperation
- Begin with increased coordination on robotic exploration missions
- Approach cooperation on a step by step basis focusing on individual projects
- Work in earnest to identify possible international interests and roles, and encourage inter-agency contacts
- Harmonize visions and roadmaps, minimize duplication, fill gaps and pursue interoperability
- Utilize international launch and logistics capabilities to provide increased redundancy and resiliency
- Adopt approaches to human exploration that anticipate and encourage significant international participation from the very beginning
- Utilize the International Space Station to prepare for exploration missions